7. NAVIGATION DAMS

A navigation dam impounds water in a pool to provide navigable depth to the next dam upstream. The spillway or outlet works of such dams is designed to pass flood flows and is regulated by gates to control outflows so as to maintain the pool elevation at an essentially constant elevation except during flood periods. In addition to gated spillway bays, some navigation dams include an uncontrolled concrete weir crest, as at some dams on the Red River, or low overflow embankments in the overbank, as at some dams on the Arkansas River. Navigation dams are of two general types: movable and fixed.

A navigable movable dam is a structure consisting of a number of wickets that can be raised individually to impound a pool at low flows (when traffic uses a lock to pass the dam) and lowered to the streambed to pass flood flows. During high-water periods, traffic can bypass the lock and pass over the dam in the lowered position. Designs of wickets vary, but the structural members supporting the damming surface are hinged to lie flat on a concrete sill at bed level when the dam is open, Figures 7.1 and 7.2. Navigable movable dams are suitable only in special cases where the lift is relatively low, the bed is stable, and there are distinct non-flood and flood periods with river stages high enough for open-river navigation for a significant part of the year.

A fixed navigation dam is a structure with streamflow passing over the top of the dam, through a spillway (either gated or ungated), or through tunnels. Fixed low-head navigation dams are of various types, ranging from the rock-filled timber cribs used in older projects to the low gated concrete crests set at about bed level generally used today, Figure 7.3. The typical design for the Arkansas River navigation project, shown in Figure 7.3, has piers on a broad-crested weir, movable spillway gates, a stilling basin, and protective stone blankets upstream and downstream of the dam to protect the river bed against scour. A similar spillway design was used for dams on the recently completed Red River navigation project, Louisiana. Design of the dam foundation depends on the nature of foundation materials at the site. Design of the piers and operating bridge depends on the elevation of high water and the size and type of gate and operating machinery used.

7.1 Navigable Movable Dams

Navigable movable dams include a navigable pass for passage of tows without locking. A navigable pass must provide sufficient clearance width for the safe passage of traffic and must have sufficient depth for tows of design draft, including depth to allow for overdraft and tow squat. Model studies indicate that a navigable pass should have a minimum cross-sectional area 2.5 times the area blocked by a loaded tow. Current direction should be aligned normal to the axis of the pass, and velocity through the pass must be low enough to permit passage of an upbound loaded tow of the horsepower operating on the waterway. Navigable pass widths at Corps of Engineer projects range from 200 ft on the Ouachita River to about 1200 ft on the Ohio River.

The Corps of Engineers still operates a few dams with older wicket gate designs, such as shown in Figure 7.1, on the Ohio and Ouachita Rivers and the Illinois Waterway, but such designs are no longer being constructed.

Canalization of the Ohio River was initially completed in 1929 with 50 low-lift locks and dams, all with wooden wickets and a 110- by 600-ft lock chamber. Replacement of those structures with 19 locks and dams was initiated in 1954. Eighteen of the replacement structures are high-lift fixed dams with 1200-ft locks. The last, and most downstream, structure is Olmsted Locks and Dam currently under construction about 16 miles above the confluence of the Ohio and Mississippi Rivers, replacing the old Ohio River Locks and Dams 52 and 53. Olmsted is the only replacement dam on the Ohio River that uses wickets, Figure 7.4. A unique centrally-controlled hydraulic lifting mechanism was considered to raise the 220 wickets for the Olmsted project, Figure 7.2. However, a manual operating system from boats is planned at this time. The Olmsted wickets will be 25.5 ft high and 9.2 ft wide; wooden wickets at the existing dams are about 14 ft high and 4 ft wide. At Olmsted, the wickets will be placed on a concrete sill with a baffled stilling basin with a sloping endsill, Figure 7.2.

7.2 Spillways

Spillways for low-lift navigation dams are usually designed with sufficient flow capacity to limit the backwater effect of the structure to about one foot for the project design flow. Where raising flood levels more than one ft is locally acceptable, as for some dams on the Red River, it may be more economical to obtain additional flowage easements and use fewer spillway gates, as discussed in Appendix B. Such spillways for low dams are usually of the broad-crested type because flow over the spillway is influenced by tailwater levels for most operating conditions.

Spillways normally are set near the river bed to maximize capacity and reduce backwater and extend across the entire river. The gate sill and stilling basin may either be level across the channel or set at different elevations across the stream to conform to the natural river cross section, preserve natural flow distribution across the channel, and minimize obstruction of the flow area when the gates are fully open, Figure 4.1. The spillway at Lock and Dam 4 on the Arkansas River was set at two elevations, with the high section at the opposite bank from the lock (where deposition occurred prior to project construction). After 15 years of operation, the benefits of the stepped crest are considered negligible, and a level crest elevation would be recommended (Corps of Engineers, 1987).

Spillways for navigation dams sometimes include uncontrolled overflow crests, depending on local conditions and optimization studies analyzing the costs of providing additional spillway gates needed to pass the design flow with about one foot of swellhead at the structure vs the combined costs of fewer gates and flowage easements needed due inundation of additional lands upstream. Also, it is sometimes desirable to provide additional flow capacity on the overbank to minimize backwater effects. Overflow embankments on the overbank are set as close to the overbank ground level as feasible to best utilize flow capacity of the overbank, and such embankments should be at least three ft above the navigation pool to allow for variation in pool levels, wind setup and wave runup.

On rivers where low dissolved oxygen levels during low-flows present a water quality problem, special measures may be needed to reoxygenate water discharged over the spillway. At Locks and Dams 4 and 5 on the Red River, Louisiana, one spillway bay has a hinged crest which draws warm water from the surface of the pool and discharges it onto a baffled chute, as discussed in Appendix B.4. Turbulence on the baffled chute increases dissolved oxygen levels.

Hydraulic models of spillways are employed to determine:

a. Minimum crest length in the direction of flow and shape of the downstream face of the sill to ensure that there is no separation of the nappe from the sill and no undulating jet action for all partial gate openings for the expected range of pool levels and various stilling basin elevations, and no serious negative pressures on the gate sill.
b. Optimum shape of gate pier nose.
c. Spillway rating curves.
d. Stilling basin performance curves for the expected range of tailwater levels.
e. Riprap requirements downstream of the stilling basin.

Low-head navigation structures have four possible flow regimes, as shown in Figure 7.5, depending on the effects of gates, tailwater elevation, and flow through the structure.

7.3 Spillway Gates

Various types of spillway gates are used, depending on spillway operating requirements and costs. If more than one type is suitable for a particular case, selection is based on cost. Where passage of ice or debris downstream through the dam requires wide gate openings, submergible gates (roller, tainter, or vertical lift gates) are used. These gates can be raised for normal operation, with discharge under the gates, but can be submerged below upper pool level to pass ice or debris over the top. If the range of stage is large, vertical lift gates may be more economical than tainter gates with very long arms. Where passage of ice or debris is not a problem, either tainter gates or vertical lift gates are generally used. Hinged crest gates and baffles on the downstream spillway face were used at two dams on the Red River Waterway where low dissolved oxygen levels were a problem in extreme low-flow periods. The hinged crest gates draw water from the warm surface level of the pool and discharge it onto the baffled spillway face where turbulence oxygenates the flow.

Tainter gates are a segment of a cylinder mounted on radial arms that rotate on trunnions embedded in piers on the spillway crest, Figure 7.6a. The gate consists of a skinplate over a system of beams that transmits the water load on the gate to the radial supporting arms. The gates may seal against the top of the sill, or may lower past the sill for passage of water (and ice and debris) over the top of the gate, Figure 7.6b. Gates designed for submergence have the skinplate extended over a rounded crest and down the lower face of the gate. Tainter gates are raised and lowered by chains or cables at the ends of the gates and are less resistant to torsion than are roller gates, but for short spans they are less costly than roller gates of comparable height. It is essential that these gates be designed to be raised above the design flood flow line so as not to raise flood levels and not to endanger the gate. Clearance is usually from one to 5 ft above the probable maximum flood. It is desirable, but not mandatory, that the trunnions be above high water, and trunnion elevation is set above most flood levels, so that submergence occurs only 5 to 10 percent of the time. Gate vibration has been a problem when tainter gates operate under submerged flow conditions at some dams. Tainter gates have been designed with heights in the range of 75 ft and lengths of up to 110 ft. Where extremely long arms would be required, it is not practicable to use tainter gates.

At Marseilles Lock and Dam on the Illinois River, non-submersible tainter gates on the spillway were replaced by submersible gates in 1987 to skim ice and debris over the top of the gates with much smaller discharge than required to draw the material under non-submersible gates. The gates, Figure 7.7a, were model tested with two spillway profiles, Figure 7.7b, and test data indicated that the crest shape had little or no effect on discharge characteristics of the structure. The data indicated that the Type 1 crest would be unstable due to vibration.. The Type 2 crest was adopted, and the gate was modified to extend the gate end shields near the piers, Figure 7.7c, to decrease the clearance between the shield and pier from 4 inches to 0.5 inches; the gate to sill clearance of 1 inch was maintained. The gates have operated for several years without vibration problems.

Roller gates are metal cylinders with ring gears at each end that travel on inclined metal racks on the piers, Figure 7.8. The roller gate is braced internally and acts as a beam to transmit the water load to the piers. Water, ice, and debris can be passed over the gate, and the gate can be raised to pass water under the gate. Roller gates are raised and lowered by a chain around one end of the gate operated by a hoist mounted in the pier. Water can be admitted to or released from the interior of the gate to change the gate's buoyancy, and the rolling movement of the gate and limited friction contact at the seal make roller gates easy to operate. They have been designed with heights up to 30 ft and lengths up to 124 ft on pile foundations and 150 ft on rock foundations.

Vertical lift gates have a skinplate over horizontal girders that transmit the water load to the piers, Figure 7.9. High piers are required for the gates in the fully-raised position above high water level. To minimize gate vibration, the gate lip in contact with the flowing water is kept as narrow as possible. Vertical lift gates are mounted on wheels or rollers to permit movement under water load, and are raised by chains at both ends, with the entire weight carried by the chains. The gates move vertically in slots in the spillway piers and seat on steel sills mounted flush on the spillway crest. Vertical lift gates have been designed for heights up to 60 ft and for spans in excess of 100 ft. When very high gates are required, a vertical lift gate may be designed in two or more horizontal sections (leaves) to reduce the required hoist capacity, reduce pier height, reduce damage to fingerlings passing downstream, facilitate passing of ice and debris, or simplify design of the ogee crest.

Hinged crest gates, or flap gates, of the type used on some recently constructed spillways on the Red River waterway, can be used to pass warm water from the upper level of the pool or to pass debris and ice. Hinged gates consist of a skinplate that transmits water pressure to an internal system of girders. They are operated by a hydraulic piston and rotate about a hinge on the weir crest and form a part of the crest when in a lowered position, Figure 7.10. The hinged crest gate used at dams on the Red River waterway is described in Appendix B.4.

7.4 Spillway Piers

The nose of ogival spillway piers on the Arkansas River project were shaped so that pier radii meet to form a 90-degree angle at the leading edge of the pier, Figure 7.3c, and a structural steel angle was embedded into the nose to protect the piers from damage when hit by loose barges. It has been found that the sharp steel angle tends to rip open barges, causing them to sink upstream of the piers. The steel nose edge has proved very efficient hydraulically for uniform gate openings, but when there is a difference in gate settings, it causes a separation of flow from the face of the pier on the side passing the greater discharge. An ogival shape with rounded leading edge is recommended (Schmidgall, 1995).

7.5 Ice

In cold climates, such as on the Upper Mississippi River, traffic ceases for several months during the winter period. However, the locks and navigation dams are operated throughout the winter to pass winter flows and ice. Passing ice is handled in different ways at the various projects. The primary factor controlling ice passage appears to be velocity of the ice as it approaches the structures. To maintain pool levels during periods of low flow, it is preferable to pass ice over the top of the spillway gates or through the lock.

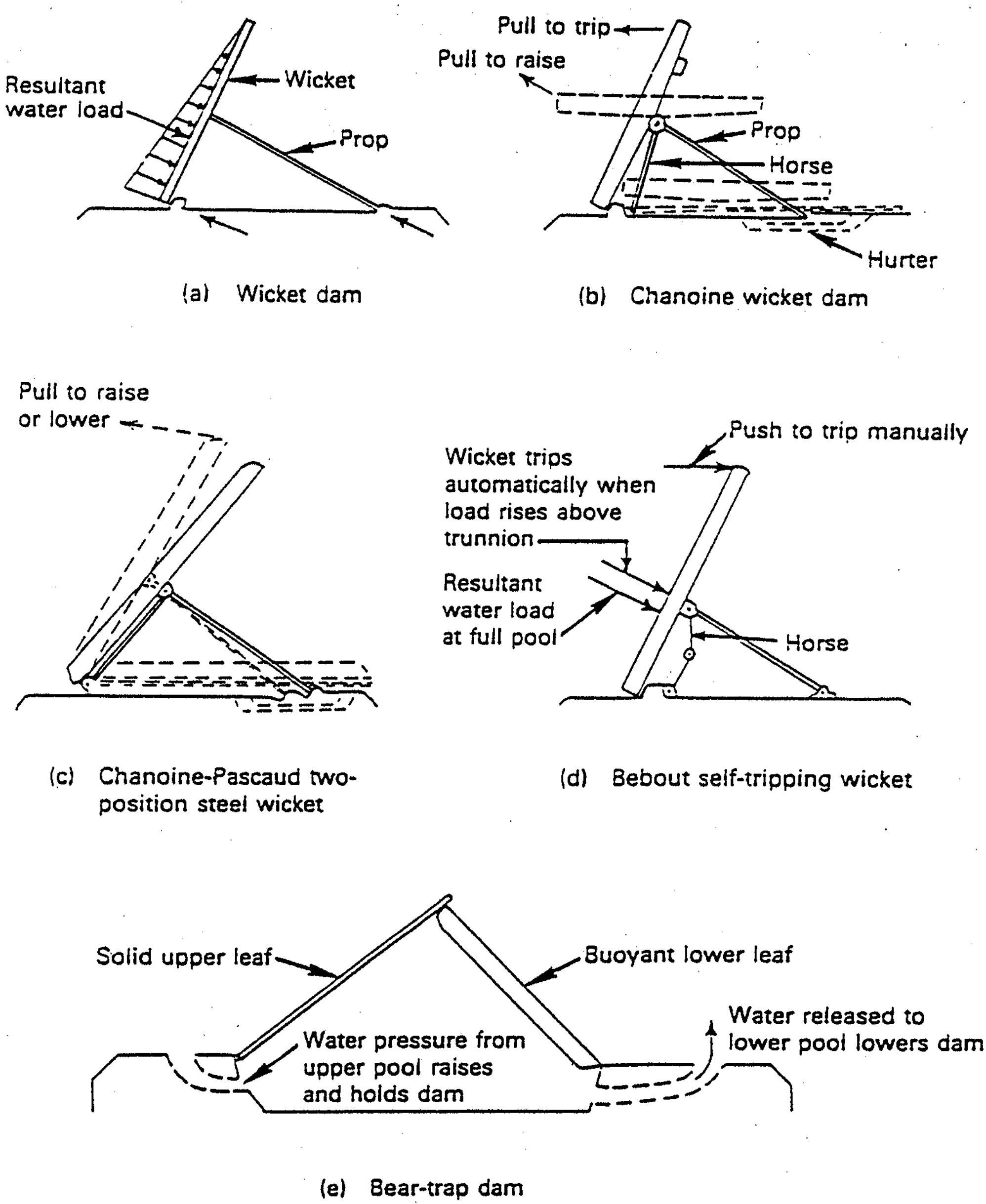


Figure 7.1 Movable dams. (U.S. Army, Corps of Engineers, 1952).

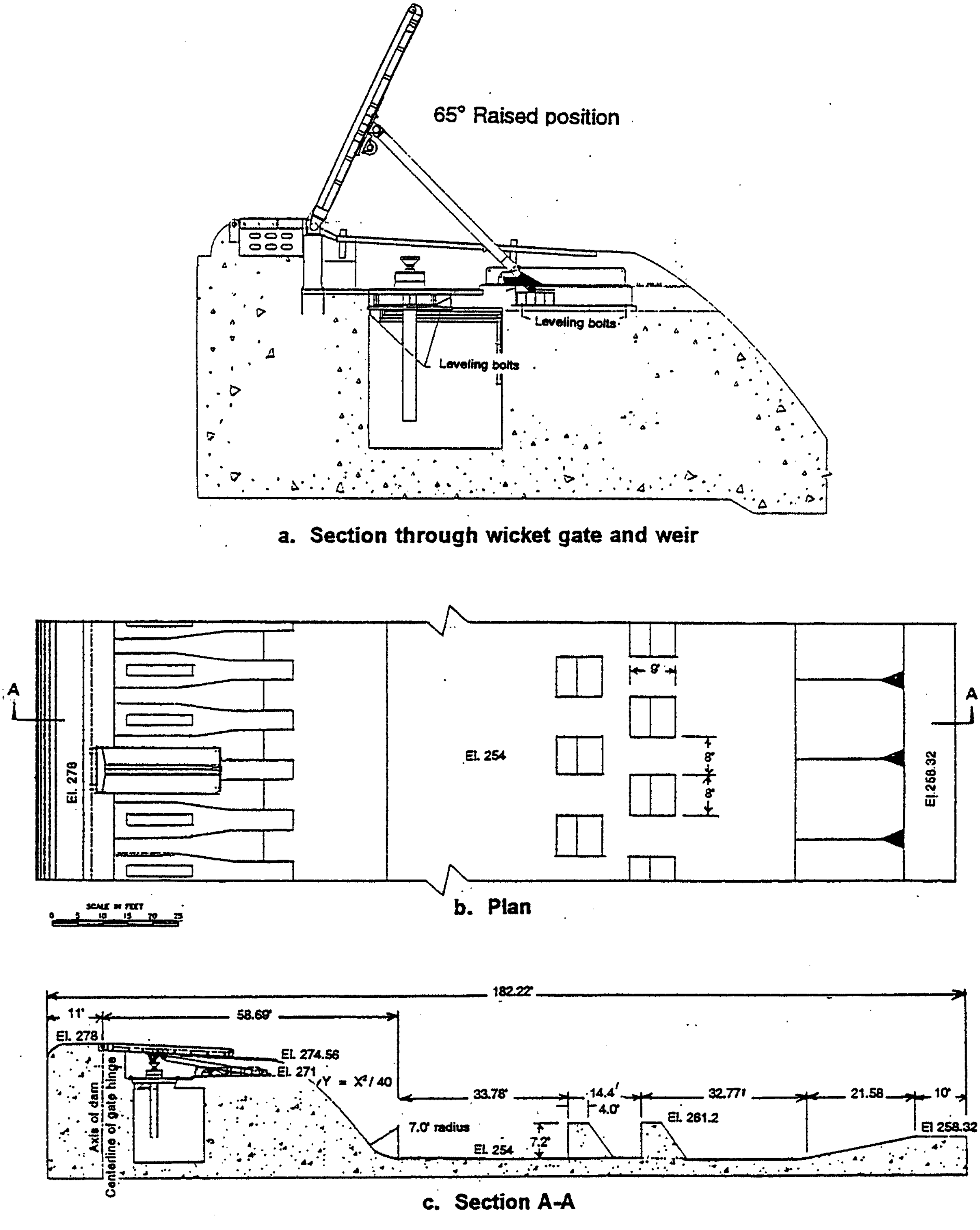


Figure 7.2 Navigable movable dam (wicket gates), spillway and stilling basin, Olmsted Locks and Dam, Ohio River.

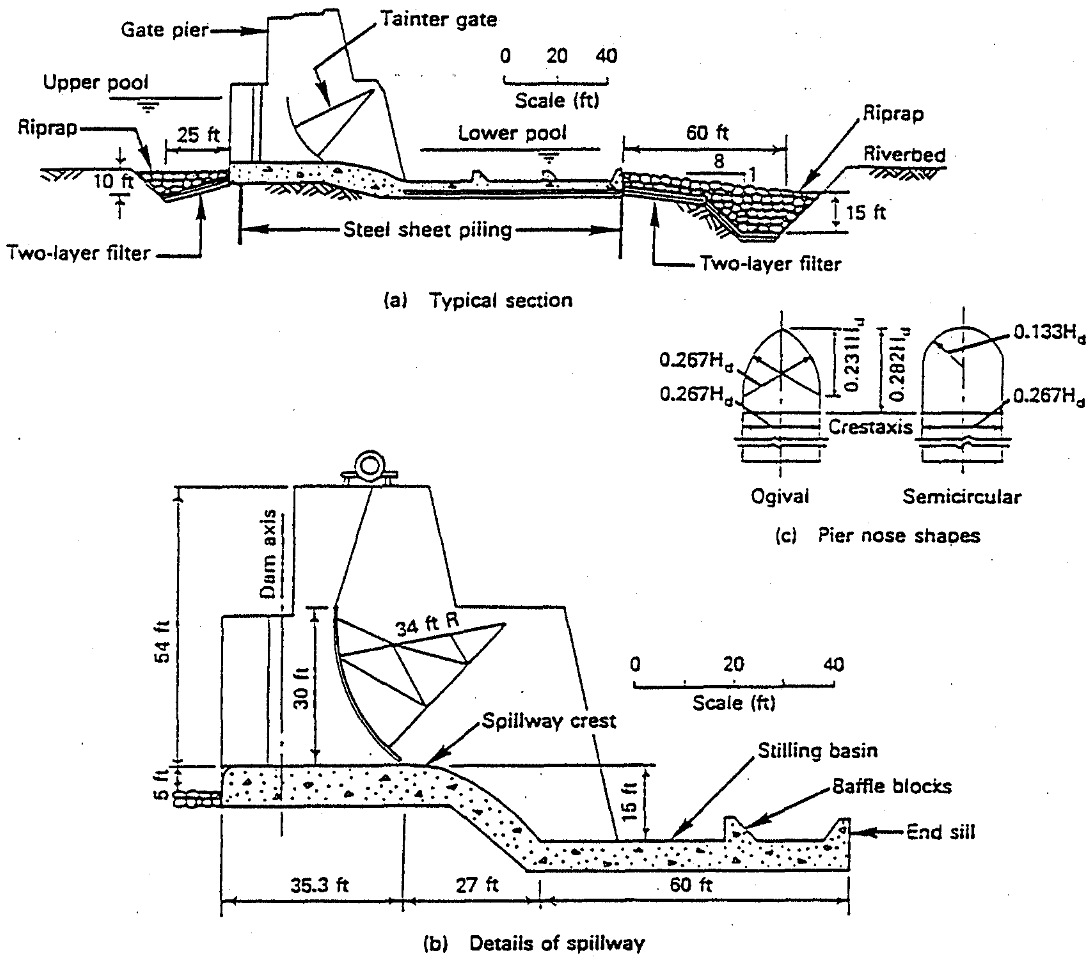


Figure 7.3 Typical non-navigable movable dam (gated spillway), Arkansas River. (Grace, 1965)

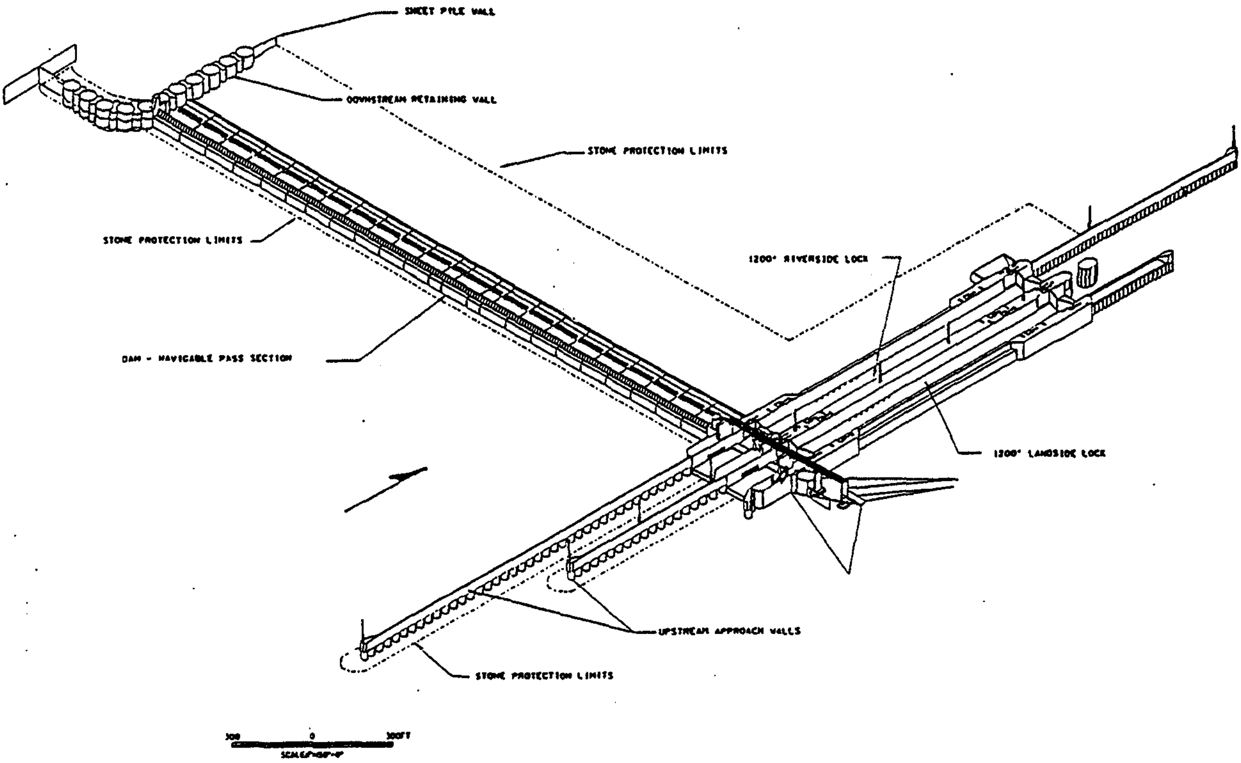


Figure 7.4. Olmsted Locks and Dam, Ohio River.

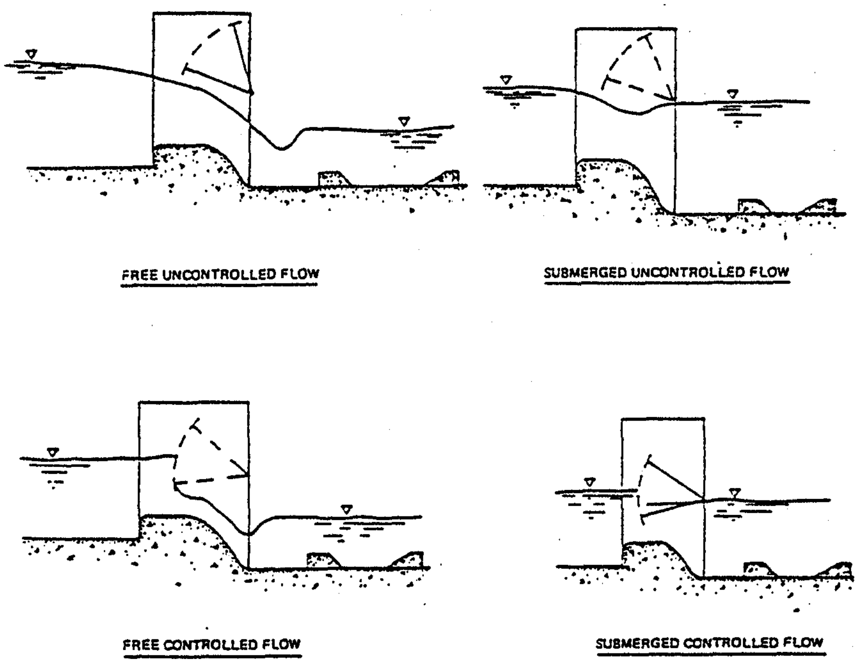
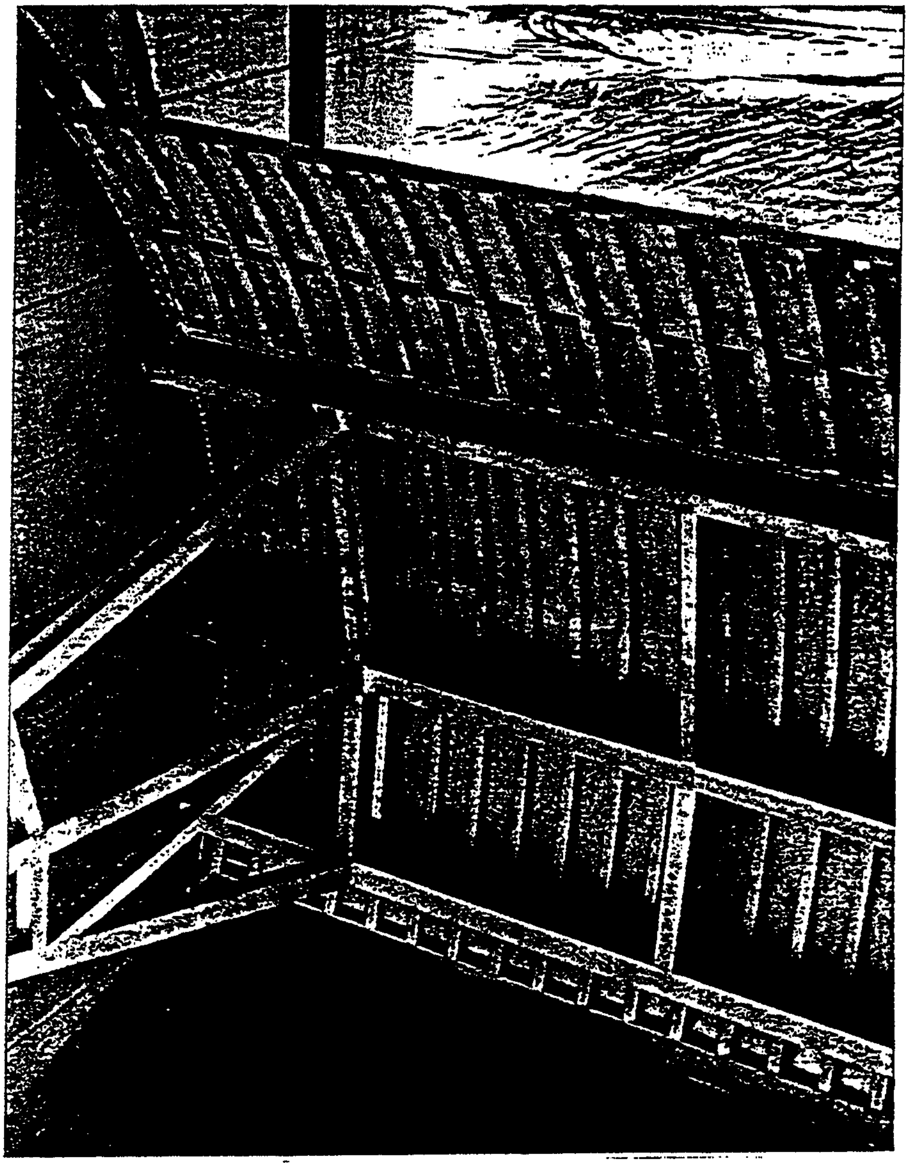
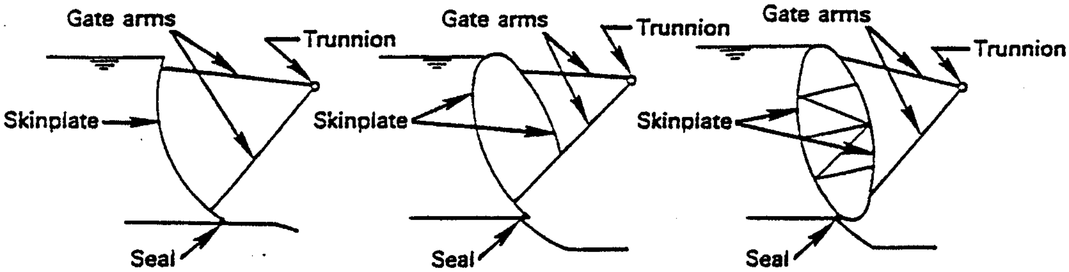


Figure 7.5. Possible flow regimes, low-head navigation weirs. (Corps of Engineers, 1987)

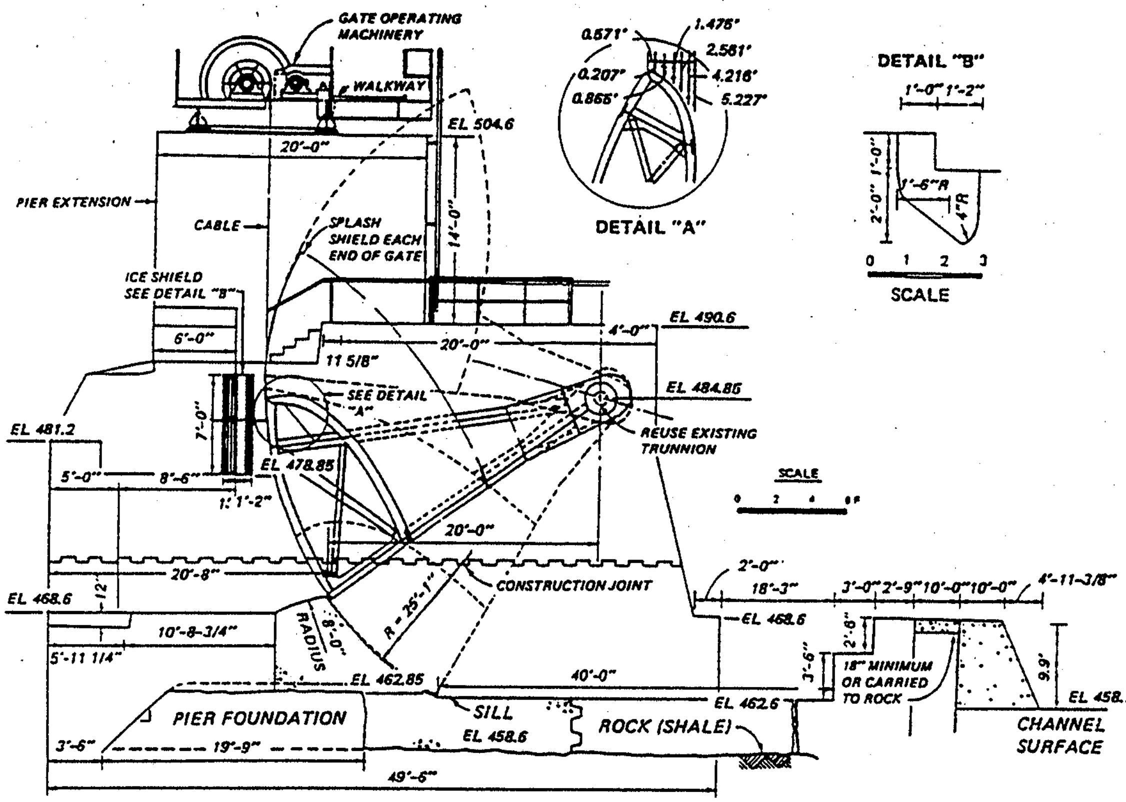


a. Tainter gate on spillway crest (downstream view). Gate is operated by a chain and travels in groove on pier face, Fort Randall Dam, Missouri River.

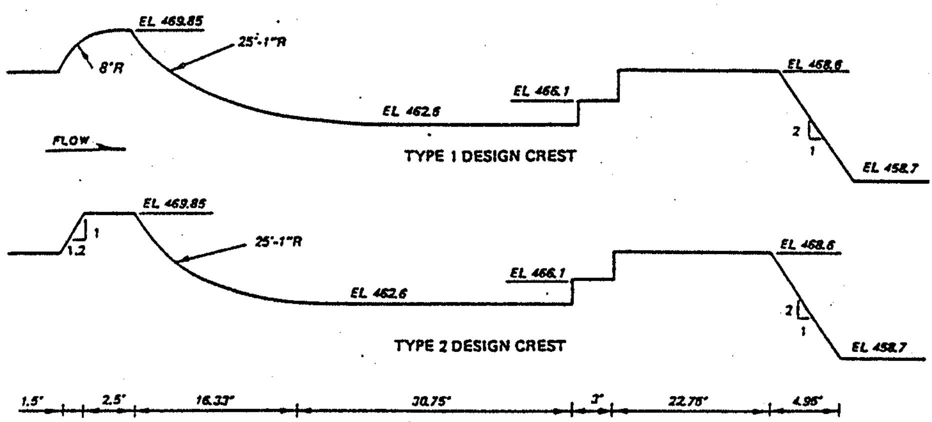


b. Tainter gate seals. (U.S. Army, Corps of Engineers, 1952)

Figure 7.6. Spillway tainter gates.

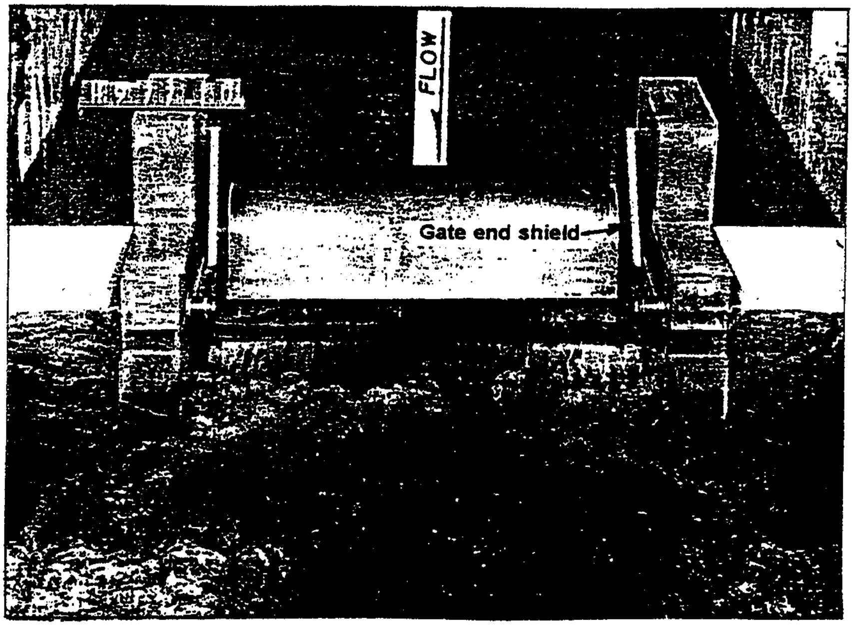


a. Details of submersible tainter gate.



b. Spillway and stilling basin for submersible tainter gate.
Alternative spillway crest shapes tested.

Figure 7.7 Submersible tainter gate, Marseilles Lock and Dam, Illinois River. (Cooper, 1989)



c. Marseilles model; flow under submersible gate. Gate open 7 ft

Figure 7.7 Submersible tainter gate, Marseilles Lock and Dam, Illinois River. (Cooper, 1989)

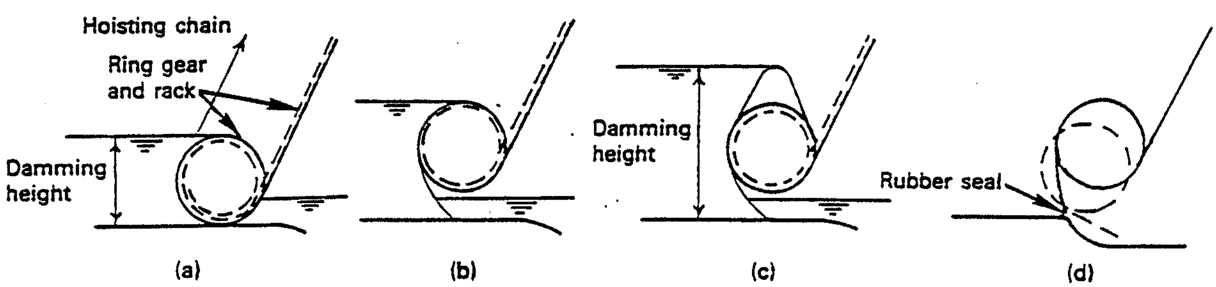


Figure 7.8 Roller gates. (U.S. Army, Corps of Engineers, 1952)

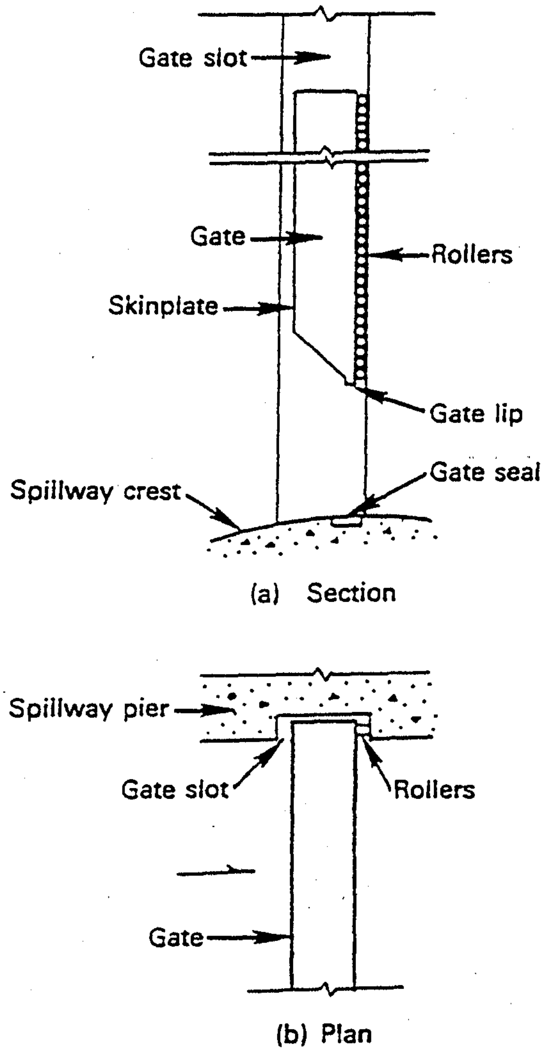


Figure 7.9 Typical vertical lift gate.

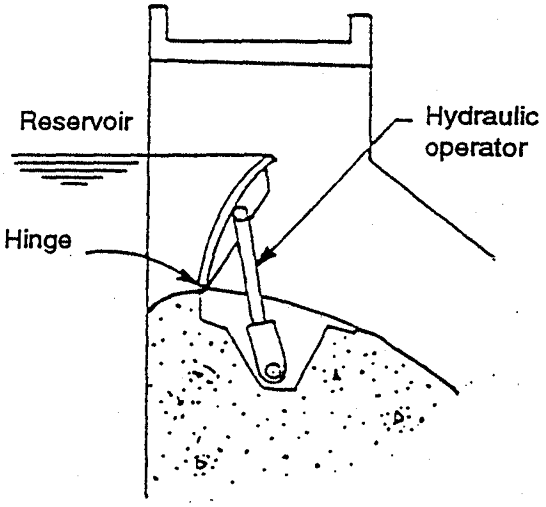


Figure 7.10 Typical hinged (flap) gate.